A Functional Near-Infrared Spectroscopy Study of Sustained Attention to Local and Global Target Features

---

A dissertation submitted in partial fulfilment of the requirements for

the degree of

Master of Science in Applied Psychology

at the

University of Canterbury

By

Neil Richard de Joux

2012

Table of Contents

List of Figures

Acknowledgements

Firstly I would like to thank my supervisors Deak Helton and Paul Russell for their amazing guidance, advice and support throughout the course of this research. Without their help I would never have gotten this far in my studies.

I would also like to thank my Mum and Dad for supporting me through my studies, feeding me through the holidays, letting me borrow the car and wasting all the petrol, and for not being too disappointed that I didn't become a geologist or a teacher.

Big thanks are also required for the APSY crew for making these past two years amazing and hilarious. The computer room banter, initiation, the All Whites night and the parties at Mikes place were all highlights, and made all the hard work worth it.

To all my non-APSY friends, thanks for putting up with me and my 'too busy to hang out' ways throughout the years. Hopefully now with a little bit more spare time on my hands we can all catch up for ice cream.

I would not like to thank the earthquakes.

Dedicated to the steel mill workers of America... keep on reaching for that rainbow.

1. Abstract

There has been extensive research investigating the differences between global and local feature discrimination. The role that global and local feature discrimination has in sustained attention tasks however has been relatively neglected. In the current research, participants were required to perform a sustained attention task requiring them to engage in either global or local shape stimuli discrimination. Reaction times to local feature discrimination revealed a quadratic trend with time-on-task, with performance levels showing a decline before returning to initial levels towards the end of the task. This trend was not found in the global shape discrimination condition. Functional near-infrared spectroscopy (fNIRS) was employed to assess hemispheric cerebral oxygenation during the tasks. It was found in both conditions that there was greater oxygenation in the right hemisphere compared to the left hemisphere. It was also found that right hemisphere oxygenation increased with time-on-task. Left hemisphere oxygenation decreased during the global task, while it increased during the local task with time on task. Total cerebral oxygenation, collapsed over both hemispheres, increased more over time in the local discrimination task than the global discrimination task. The performance data and the fNIRS results suggest an increased utilization of bilateral cognitive resources with time-on-task in the local discrimination condition, but not in the global discrimination condition. Results and implications are discussed.

2. Introduction

2.1. Introduction to Vigilance

For the simple objective of survival, humans and other animals are required to scan their immediate environments for two particular classes of target, threats and food. This need is still required in the animal kingdom, with animals needing to scan their habitats for predators while also scanning for edible food sources. In some cases, these food sources are extremely specific, meaning that these animals must search for unique, critical targets in a background of non-critical stimuli. For most people, the need for critical target detection in the natural context (predators and prey) is no longer paramount, but instead has been replaced by the requirement to scan artificial displays. Increasingly human activity, especially in workplace environments, involves searching for information on video screens and other information displays.

Technological advances since the industrial revolution have resulted in dramatic changes to the way that humans perform many tasks in workplace environments, in particular those workplace environments that once required a large amount of physical labour. Whereas in the past a large proportion of tasks were performed manually, the modern factory has shifted towards a more automated approach utilizing machines which are capable of much heavier lifting and much more precise movements. The individuals working in these more automated environments have transitioned from a physical labourer to a role of an observer, required to monitor systems for extended periods of time for anomalies, and stepping in for short periods of manual control when specific problems within the systems are identified. This form of supervisory work mediated by automation is not unique to the physical labour workplace. A doctor or nurse working in an emergency department, for example, will typically engage in extended periods of monitoring medical equipment and the statuses of patients in their care. During the course of this monitoring they may notice a change in a patient’s condition, which will require them to engage in more thorough or even ‘hands-on’ activity directly with the patient.

There are also a number of non-workplace related activities which require this form of behaviour. Driving a car for example requires an operator to be constantly scanning the environment for hazards, riding a bike requires the same. Sports and other recreational activities may also require that an individual performs scanning of their immediate environment before performing a manual action. In fact, almost any human or animal activity requires in some part the continuous monitoring of environments in which that activity is performed.

When reduced to a purely systems-based perspective, these workplaces and activities tend to follow the same basic principles regardless of that workplace’s or activities’ specific tasks and goals. Essentially, those individuals in these kinds of environments will maintain extended periods of observation and monitoring while searching for a unique target or set of targets. Once these targets have been identified a specific response will be performed. Often this response is one which requires assuming manual control of the system in order to make adjustments to bring the system in line with the desired operating path.

The task of monitoring for rare and unique stimuli while ignoring more frequently occurring and generic stimuli has been termed a vigilance or sustained attention task (Davies & Parasuraman, 1982; Helton & Warm, 2008; See, Howe, Warm & Dember, 1995). These terms, vigilance and sustained attention, are generally used interchangeably throughout the literature. The current research focuses on the topic of vigilance, and will continue to use both of these terms when referring to these types of tasks.

2.2. A History of Vigilance Research

The first scientific research in the area of vigilance is commonly attributed to Mackworth (1948). The specific problem Mackworth was investigating related to the gradual decline in performance over time by Royal Air Force (RAF) cadets working as radar operators in World War II. These cadets were required to detect submarines over a 1.5 to 2-hour time frame. Over the duration of these watch periods however, cadets displayed a marked decrease in task performance. In order to determine the point at which performance reached critical levels (i.e. when cadets were failing to detect targets or were taking too long to detect targets), Mackworth set about simulating this radar-detection environment in the laboratory. A clock-face task was set up in which participants were required to respond when a clock hand jumped two spaces instead of the typical one space. The event of the hand jumping two spaces occurred infrequently relative to the hand jumping one space. Mackworth found that participants' performance (in terms of correct detections) decreased markedly over time on task, much like the phenomenon found in the RAF cadets. This effect has since been labelled *the vigilance decrement*.

While the clock-face task was designed specifically to simulate the radar detector environment, similar types of experiments simulating different types of environments have yielded similar results. Situations involving luggage scanning, medical monitoring, driving a car, airplane operating, and other generic system monitoring tasks have been found to show the vigilance decrement (Davies & Parasuraman, 1982; Hancock & Hart, 2002; Ballard, 1996; Damos & Parker, 1994). Again, the common aspect to all of these situations is that the operator is required to sustain a vigilant state for an extended period of time and respond to unique signal which occur at both infrequent and random intervals.

There has been a large amount of research on the topic of vigilance and the vigilance decrement, and there is an extensive background literature. Researchers have investigated and examined a number of differing factors which can affect individual performance on vigilance tasks, including manipulation of the salience (perceptual conspicuity) of the stimuli used, the frequency of the target occurring (target probability), the rate of stimuli presentation (event rate), and the type of responding required by participants (Wilkinson, 1969; Ballard, 1996; Biebuyck, Weinger & Englund, 1990; Hollands & Wickens, 1999). Researchers have also investigated patterns of brain activation throughout the course of a vigil, however this specific line of inquiry has not experienced a large amount of focus when compared to other areas regarding vigilance. Study of brain activation during vigilance tasks has potential to enhance understanding of the causes of the vigilance decrement, and may assist in explaining trends of responding found in certain settings. The specific topic to be focussed on in this research is how local or global target stimuli may affect both performance and brain activity during a vigilance task.

2.3. Global and Local Objects

Vigilance research has largely neglected the issue of whether global or local features of objects have a significant effect on an individuals' performance during sustained attention tasks. Almost all visual shapes or objects that people see are organized in a hierarchical way such that an overall global shape is composed from smaller shapes and features. A square for example is composed of four straight lines ordered in a formation to represent the box shape. These squares may in turn comprise a small portion of an even larger shape, and so on until a large, complex shape or object is formed. Local and global object discrimination is then required of an individual when asked to look at either the shape as a whole, or at the shapes which make up the overall object.

The subject of global versus local feature detection itself has been investigated in a range of research, however the topic of global-local feature detection and its’ role on vigilance performance has been relatively unexamined by researchers. Navon (1977), Kimichi (1992) and Lamb and Robertson (1990) all appear to have investigated the role of global and local feature discrimination in basic perception research rather than vigilance research. The majority of global-local studies provide an external prompt to the participant before figures are presented. This acts as both a memory aid and an arousal aid to the participant throughout the task. These participants are therefore not required to sustain attention, and therefore vigilance is not a feature of these studies. There are, however, some examples of research with global and local objects being conducted without these external prompts given to the participant. Flevaris et al. (2010, 2011a, 2011b) studies utilized the block trial method which will be used in the current research. These block trials had the participant continuously exposed to stimuli with no memory aid of the target object they were to respond to. These studies were mainly focussed on the perception of local and global objects rather than the vigilance task itself, and time-on-task effects were not examined. The critical issue of the vigilance decrement was unexamined in these previous global-local studies.

Helton, Hayrynen and Schaeffer (2009) did, however, investigate the effects that global-local target discrimination has in vigilance tasks. They used global-local letters, which were letters composed from smaller letters. These letters were similar to ‘Navon objects’ used in pioneering work by Navon (1977). Participants in the Helton et al, study were asked to respond to either the global letter or the local letter amongst a series of distracter targets. They found that reaction times in the global feature discrimination condition were slower than those in the local feature discrimination condition. Helton et al. also investigated differences in cerebral activation between hemispheres using the tympanic membrane temperature (TMT) method. This method assesses inner-ear temperature using an ear thermometer in both pre- and post-task states, with temperature changes indicating that a change in cerebral activity has occurred. It was found that there were differences in TMT readings across hemispheres, and that these changes also corresponded with performance differences in global or local target discrimination conditions. Both the performance data and the corresponding TMT readings indicated that higher levels of cognitive fatigue were found in the global discrimination condition. This is intriguing given prior research indicating a global precedence effect – that global shapes are typically recognized more quickly than local shapes (Navon, 1977). Given the global precedence effect, a ready assumption may have been that vigilance would be better for tasks requiring global discrimination; but this may not be the case.

2.4. Brain Activation during Vigilance

Previous research has demonstrated an increase in metabolic activity in the right hemisphere of the brain compared to the left hemisphere during tasks requiring sustained attention (Stroobant & Vingerhoets, 2000; Warm, Matthews, & Parasuraman, 2009; Shaw et al., 2009). This trend for right hemisphere dominance in vigilance tasks has been found in previous research utilizing a number of different brain imaging techniques including functional magnetic imaging (fMRI), positron emission tomography (PET), transcranial doppler sonography (TCD), and functional near-infrared spectroscopy (fNIRS) (Berman & Weinberger, 1990; Buchsbaum, et al., 1990; Helton et al., 2007; Hitchcock et al., 2003; Parasuraman, Warm, & See, 1998; see Helton et al, 2010 for a more in depth perspective). This trend is further indicated by research involving commissurotomized patients (where the corpus callosum of a person is severed, restricting the transfer of information between hemispheres) , which found superior performance for stimuli which are presented to the right hemisphere than to stimuli presented to the left hemisphere (Diamond, 1979a, 1979b).

Research by Lux et al (2004) and Yamaguchi, Yamagata, and Kobayashi (2000) also suggests that the right hemisphere is dominant when an individual is required to engage in discrimination of global object stimuli, while the left hemisphere is dominant when an individual is required to engage in local object discrimination. Indeed, Fink et al. (1997a, 1997b) studies using Navon objects found that there was a compelling case to believe local feature discrimination and global feature discrimination possess some degree of hemispheric specialization in regards to their processing in the brain. Posner and Peterson (1990) outline a number of models of attention which suggest that although systems for both pattern recognition and maintenance of attention are connected via neural pathways, their functioning in the brain is divided. These pathways are therefore required to be integrated during the performance of sustained attention tasks, which may result in performance differences in relation to the type of stimuli that is used. The implication of this is that when global stimuli discriminations are involved in sustained attention tasks, it places higher resource demands on the right cerebral hemisphere. This is due to the sustained attention task as well as the global object discrimination both appearing to be more right hemisphere intensive. However when local object stimuli discrimination is involved in sustained attention tasks, the result is that bilateral brain activity is increased. Helton et al (2009) findings suggests that performance on vigilance tasks is disrupted to a larger extent during tasks where global, rather than local, feature discrimination is a requirement. Nevertheless, this difference between right hemispheric dominance in the global discrimination condition and increased bilateral activation in the local discrimination condition has yet to be fully determined; Helton and colleagues did not examine cerebral activity during the vigilance task itself.

In long duration tasks requiring sustained attention with local object discrimination, bilateral activation may be advantageous to an individual. An increase in bilateral activation would result in an overall increase in cerebral resources to be directed towards the vigilance task. This would mean that an individual would be able to sustain attention to the task for a longer period of time. In turn, this could result in better performance overall. It has also been stated that when brain functions are required to use the same cerebral territory they may interfere with each other's functioning (Kinsbourne, 1982). The bilateral activation found in local object discrimination should therefore have an advantage over the right hemisphere dominance of global object discrimination, as the brain functions required in the task do not have to compete with each other to the same degree. Therefore, local discrimination performance may be increased due to either the overall resource level being increased, through the reduced need for the brain to use one specific area to perform essential brain functions, or a combination of these factors.

There is however a contrary argument that favours global stimuli in a vigilance task despite both global stimuli and sustained attention being more right lateralized. Because the right hemisphere is adept at both global feature processing as well as the maintenance of sustained attention, benefits from the coordination of two processes in the one hemisphere may outweigh costs of potential mutual interference that was considered in the previous paragraph. Therefore the current research assesses the relative cerebral activation when participants complete local (presumably activating the left hemisphere) and global (presumably activating the right hemisphere) vigilance tasks.

Participants were required to perform a sustained attention task involving either global or local target discrimination. The research followed a similar format to that found in Helton et al. (2009) with the addition of a number of key differences. Discrimination objects in the current research involved shapes made from smaller shapes, rather than letters composed of smaller letters as used by Helton et al. (2009), allowing the generality of their findings to be assessed. The duration of the task was also extended in the present study (28 minutes vs. 20 minutes), which allows a greater examination of the stimuli's effect on sustained attention, the vigilance decrement and on cerebral activation. Additionally the periods of watch was shortened (2 minutes vs. 4 minutes) in order to examine closer the changes which occur with time-on-task. Finally, whereas the previous research used TMT, the current study uses fNIRS as its measure of cerebral activity. This has a number of advantages in regards to data gathered as well as ease of use (see Section 2.8).

2.5. The Vigilance Decrement and Stress

The cause of the vigilance decrement has been the subject of extensive debate by vigilance researchers (Helton & Warm, 2008; Brache, Scialfa, & Hudson, 2010; MacLean et al., 2009). From these debates there have emerged two competing theories, the resource depletion theory and the boredom-mindlessness theory. While the debate over these theories on the phenomenon of vigilance decrement is not a central point in relation to the current research, it is important in the general explanation of vigilance itself to explore them, and they do have some implications in regards to the measurements used in this study.

The dominant theory in vigilance decrement is the resource theory (Helton & Russell, 2012). The resource depletion theory of vigilance decrement states that the vigilance decrement is a result of an inability to maintain high levels of sustained attention over an extended period of time due to limited cognitive resource availability to them (Kahneman, 1973). In other words, they reach a critical point at which they are under-resourced and are unable to match the cognitive requirements of the task. A common model used to explain this theory refers to a ‘resource reservoir’, a finite pool of cognitive resources. Vigilance tasks require that an individual continuously monitors their environment for critical signals, which in turn means that these individuals do not receive the opportunity for breaks or a rest period. This places the individual into an elevated level of mental demand, which slowly drains the cognitive resources of the individual and in turn leads to vigilance decrement over time.

There are a number of factors which could influence this hypothetical resource reservoir and exact amount of resources available to each person. Sleep, stimulants, individual differences, environmental conditions and previous experience could all affect resource levels. This accounts for individual differences found in tasks.

In competition with the resource depletion theory, the boredom-mindlessness theory suggests that individuals become bored with vigilance tasks due to insufficient external stimulation from the stimuli. In other words, they are under-stimulated by the task. Due to vigilance tasks typically being subjectively boring or repetitive, individuals become bored and their attention drifts away from the task over time (Scerbo, 1998; Manly et al., 1999; Green et al., 2009). This results in individuals losing focus on the task at hand, leading to a decline in performance. This drift in attention in sustained attention tasks has been found to be characterised by an increase in task-unrelated-thoughts as the duration of the task increases (Robertson et al., 1997).

The resource theory of vigilance has been used much more widely to explain findings in a number of studies (Davies & Parasuraman, 1982; Helton et al., 2005; Helton, Shaw, Warm, Matthews, & Hancock, 2008; Temple et al., 2000; Warm, 1993). Due to this, the current research takes resource theory perspective. An important point to gather from previous research is that sustained attention tasks may be found by some to be stressful events (Warm, Parasuraman & Matthews, 2009). This may appear counterintuitive due to the apparent relative simplicity of the vigilance tasks often performed in a laboratory setting. However previous research has found that even if a task is not deemed particularly difficult, over time they cause an individual to enter a stressed or agitated state. This stressful or agitated state appears to be less compatible with a boredom-mindlessness theory of vigilance decrement, and is more easily explained with resource depletion theories.

2.6. The Measurement of Stress

Stress can be measured as both a physiological and a psychological construct. Physiological measurements of stress as a result of vigilance tasks have found increased levels of hormones released by the body into the bloodstream (Lundberg, 2005; Frankenhaeuser, Nordheden, Myrsten & Post, 1971). It has also been found that vigilance tasks can result in increased muscle tension, headaches, and restlessness (Galinsky, Rosa, Warm & Dember, 1993; Hovanitz, Chin & Warm, 1989). Other physiological measures of stress have included the monitoring of eye movements, activity in the autonomic nervous system, and cerebral blood flow (Warm, Matthews, Parasuraman, 2009; Oken, Salinsky & Elsas, 2006; Wang et al, 2005).

Aside from physiological measures of stress, it is possible to investigate the psychological effects of stress through self-report measures. These measures tend to focus on the subjective aspects involved when people become stressed. It has been found that such measures do correlate with the physiological indicators mentioned above (Matthews, 2001). However, self-report measures may be more closely related to the cognitive aspects of stress than to the physiological aspects (Matthews et al, 2002), and therefore provide a better insight into these higher level or cognitive aspects of stress. As the current research is interested in measuring differences in subjective ratings of stress as well as physical measures, it is appropriate that self-report measurement tool is used.

2.7. Dundee Stress State Questionnaire

The Dundee Stress State Questionnaire (DSSQ; Matthews et al, 1999, 2002) will be used in the current research. Four subscales of the DSSQ will be used, similar to a number of previous vigilance studies (Helton et al., 2000, 2004; Szalma et al., 2004, 2006). These subscales were Task-Related Cognitive Interference (worry about things related to the task),

Task-Unrelated Cognitive Interference (worry about things not related to the task), Tense Arousal (nervous-relaxed) and Energetic Arousal (alert-lethargic).

The DSSQ is a global self-report measure of subjective state, which is administered to participants after the task. While it would be possible to use alternative data gathering techniques, such as the thought probe method, in order to gather the required information, this later method would probably be disruptive to ongoing activity. This method involves experimenters interacting directly with the participant at specific points throughout the task in order gain insight into the participants' state at the point in time. While this could potentially allow researchers to pinpoint when certain processes begin to occur, the probing itself could adversely impact task performance and subjective state (Giambra, 1995). Furthermore, Smallwood, Baracaia, Lowe and Obonsawin (2003) identified that post-task global measures and thought probing techniques correlate reasonably well. Therefore the use of a post-task recall measure in the current research should not significantly impact upon the quality of the data gathered. In addition, it will not affect task performance. Due to its' appropriate data gathering method, clear trends in previous findings, and wide use in similar vigilance research, the DSSQ is used in the current research.

2.8. Functional Near-Infrared Spectroscopy

As stated above, stress can be measured through both psychological and physiological means, although they have slightly differing operational definitions in this case. The psychological definition of stress refers more to the subjective state of the individual. The physiological definition of stress in this case refers to fluctuations of cerebral activity as a result of vigilance tasks being mentally demanding (Warm et al, 2008, Hancock & Warm, 1989). One of the issues of using global self-report measures is that they rely on recall of past events. An individual completing such a measure would have to recall their state from a previous time frame within the experiment, which may be biased by their subjective state while completing the questionnaire (Podsakoff & Organ, 1986). Another issue that may arise is that of social desirability in responses, or responding in a manner which they deem is desired by the experimenter (Arnold & Feldman, 1981; Richman, Kiesler, Weisband & Drasgow, 1999). Additionally, we are unable to detect where changes occur during the task. This means that we are unable to determine what is occurring at the onset of the vigilance decrement, and are simply determining that it has caused an effect to the subjective state of the individual after the fact. Research has identified a link between subjective state and physiological stress reactions (Rahnuma et al., 2011), suggesting that a measurement of physiological activity could be a reflection of subjective state. Considering that the previously mentioned probing technique would be inappropriate for the current research (given the tasks high event rate), it is necessary to use an alternative, non-intrusive method of gathering physiological stress data to compliment findings regarding the subjective state of individuals. The functional Near-Infrared Spectroscopy (fNIRS), which is primarily employed to assess cerebral activation differences in local and global discrimination conditions has also been used in a range of research as a measurement of physiological stress (Tanida, Katsuyama & Sakatani, 2008; Plichta et al., 2011; Kirilina et al., 2012). Indeed, Ishii et al., (2008) investigated the use of fNIRS as an alternative technique for mental state analysis, and found results that indicate its' suitability as a tool for mental state evaluation.

The Nonin EQUANOX™ 7600 Near Infrared Cerebral Oximeter will be used for the current research (Figure 1, pg 20). The fNIRS is a technique which measures cerebral tissue oxygen saturation (rSO2). This is calculated by determining the relative amounts of oxyhemoglobin (O_2Hb) and deoxyhemoglobin (HHb) in each hemisphere. This is possible due to the unique optical absorption characteristics each possesses. The fNIRS has been determined to be a similar measure of cerebral activity to the fMRI technique, due to the relationship between decreases in HHb (which results in an increase in rSO2) with increases in blood-oxygenated-level-dependent (BOLD) signal used in the fMRI (Ekkekakis, 2009; Gratton & Fabianai, 2007). The fNIRS requires that two sensor pads are attached to the forehead of the participant throughout the duration of the task. The sensor pads emit small pulses of near infrared light throughout the task, monitoring changes in blood oxygenation and recording the results over an extended timeframe. The recorded data can then be used to analyse changes in blood oxygenation at specific points of the vigilance task. This in turn can be used to determine the relationships between brain activity and task performance and brain activity and cognitive state. Results from previous studies utilizing this technique have shown that tissue oxygenation increases along with information processing demands (Helton et al., 2007; Stevenson, Russell & Helton, 2011, Toronov et al., 2001). The fNIRS allows us to investigate a number of hypotheses in the current research. Due to the differences in hemispheric activation during vigilance tasks, the fNIRS allows us to determine whether the left and right frontal lobes show differences in activation as a result of local and global feature discrimination. Additionally, recording of changes over time allows us to examine what is occurring in the brain as the vigilance decrement occurs.

2.9. Hypotheses and Research Aims

Hypothesis 1 – Both tasks will result in higher levels of cerebral oxygenation in the right hemisphere relative to the left hemisphere.

Hypothesis 2 – The local task will result in increased cerebral oxygenation in the left hemisphere. This increase will be greater than the increase in left hemispheric oxygenation found in the global task.

Cerebral oxygenation has been found to increase due to heightened activation during vigilance tasks. It is hypothesised that this will occur again during the current research.

However differences in how target features may impact on the patterns of oxygenation are less certain. Resources being utilized or recruited by one hemisphere may cause higher levels of oxygenation in that hemisphere. Alternatively, resources being shared across hemispheres may cause greater levels of bilateral activation and cerebral oxygenation. It is therefore necessary to investigate the differences that global-local feature discrimination has on overall oxygenation levels and hemispheric oxygenation levels throughout the course of vigilance tasks. Due to previous similar research finding higher levels of cerebral oxygenation in the right hemisphere during vigilance tasks, it is hypothesized that the right hemisphere will again show greater cerebral oxygenation than the left hemisphere.

While the right hemisphere will show greater levels of oxygenation in both tasks, the local task will result in bilateral activation. This means that both hemispheres will experience greater levels of oxygenation than resting baseline in the local task. The global task will not result in left hemisphere activation above resting levels. The local task will result in left hemisphere oxygenation levels increasing, whereas left hemisphere oxygenation in the global task will not increase above baseline levels.

Hypothesis 3 – The local feature discrimination condition will show faster response times than global feature discrimination condition with time on task.

The need for resources to be directed to one specific hemisphere of the brain may cause a decrease in performance due to conflicting cognitive processes in that hemisphere. In contrast, it may cause an increase in performance due to resource optimization within the brain. These potential differences need to be investigated in order to assess what occurs when one hemisphere is required to perform multiple tasks. Due to previous similar research indicating superior performance in the local feature discrimination condition, it is hypothesized that those in the local condition will have faster response times.

Hypothesis 4 – The vigilance decrement will occur as time-on-task increases.

As this is a task requiring sustained attention, we expect that performance will generally degrade throughout the duration of the task, resulting in longer reaction times from participants. We expect that the vigilance decrement will occur in the current study.

Hypothesis 5 – There will be significant differences in self-reported subjective state for the two tasks.

The two tasks could result in different subjective responses. If the local task results in bilateral activation and the global task instead places a heavy burden on the right hemisphere, the participants may be aware of this to some extent. If bilateral activation improves performance and results in less cognitive load in the local task, then participants in that condition should indicate this by either having more opportunity to engage in task-unrelated thoughts (indicating increased cognitive resources), more energetic arousal (less fatigue), and/or lower tense arousal (less distress).

3. Method

3.1. Participants

Thirty two participants (26 male, 6 female) comprised of students from the University of Canterbury in Christchurch, New Zealand completed the study. The age of participants ranged between 18 and 32 years (M = 23.15, SD = 2.73). All participants were right handed, which was indicated by the participant and confirmed through observation of hand use while signing the consent form, completion of questionnaires and key press responses during the vigilance task. All participants had normal or corrected-to-normal vision. Upon completion participants received a $20 shopping voucher in return for their time.

3.2. Materials and Procedure

All 32 participants were individually tested in a quiet laboratory room which had no external windows but was well lit overhead fluorescent lighting that created minimal amounts of glare on the video terminal display (.22cd/m^2). Upon entering the room participants were provided with an information sheet and consent form, which contained information about the required task, the materials to be used, and the process of the experiment. If participants agreed to take part in the study they then signed the consent form prior to the experiment beginning. All watches were removed and mobile devices switched off. Participants were seated approximately 40-50cm in front of a computer screen (270mm x 340mm) which was at approximately eye level.

The participant was fitted with the Nonin EQUANOX™ 7600 Near Infrared Cerebral Oximeter. This device consists of two sensor pads connected to a central machine (see Figure 1). The sensor pads measured blood oxygen saturation levels of the participant during the task (see Section 2.8. for an in-depth technical explanation of the EQUANOX™ 7600 and how it functions). Participants were informed of the non-invasiveness of the system in order to reduce any unwarranted anxiety. The sensor pads were fitted to the participants' forehead with one pad on the left and one of the right. The central forehead was used as a point of symmetry. It was ensured that there was no hair underneath the sensors (which could disrupt the sensor functioning) and that the sinus cavities were avoided (which could compromise the results by producing inaccurately high readings). Once appropriate sensor areas were found the sensors were held in place with an adjustable head strap. The head strap, as well as the relatively short cable, somewhat restricted the participants' range of motion for the duration of the experiment. Prior to the experimental session beginning baseline recordings were taken for a five minute baseline period. This provided an appropriate index point for data analysis, as well as allowing the participant to become comfortable with the equipment. During the baseline period participants were instructed to stare at the blank screen of the video terminal display, to maintain normal breathing patterns, to avoid any unnecessary head or body movements, to refrain from speaking and to attempt to maintain a state of relaxed wakefulness. Cerebral oxygenation during the final 60sec of the baseline period provided a baseline index to be used in analysis (Aaslid, 1986). Once the baseline period was finished the participants were informed that they could begin the experiment. On conclusion of the task, the sensors and head strap were removed from the participants forehead before they completed the DSSQ post-task. Information was gathered from the near infrared spectroscopy machine via Bluetooth immediately following each experimental session.

Figure 1. The Nonin EQUANOX™ 7600 Near Infrared Cerebral Oximeter with attached cables and sensor pads.

Participants were assigned randomly to a global or local vigilance task within the constraint that groups contained equal numbers of male and female participants. Participants performed a detection task using global-local shapes, which are larger shapes formed by much smaller shapes (Navon, 1977; Helton, 2009; Helton, Hayrynen & Schaeffer, 2009). In both of the response conditions participants were required to respond to the same unique target shape, however the distracters in each condition were changed which resulted in one condition requiring local target discrimination and one condition requiring global target discrimination.

During the task participants observed a video display terminal which presented one of three shapes, one being the target stimuli while the other two shapes were distracters. Whenever the target stimuli were displayed participants were required to respond by pressing the ‘response’ key on a keyboard (the spacebar). If the shape displayed was a distracter stimuli the participant was required to abstain from pressing the key. These shapes were presented in the centre of the screen. The target shape in both global and local conditions was a large square which formed by a group of smaller circles (Figure 2). The distracter stimuli in the local target discrimination task were a large square and a large diamond both made of smaller triangles (Figure 3), while the distracter stimuli in the global target discrimination task were a large diamond made of smaller circles and a large diamond made of smaller triangles (Figure 4).

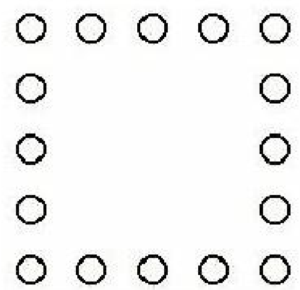

Figure 2. Target shapes for local and global conditions.

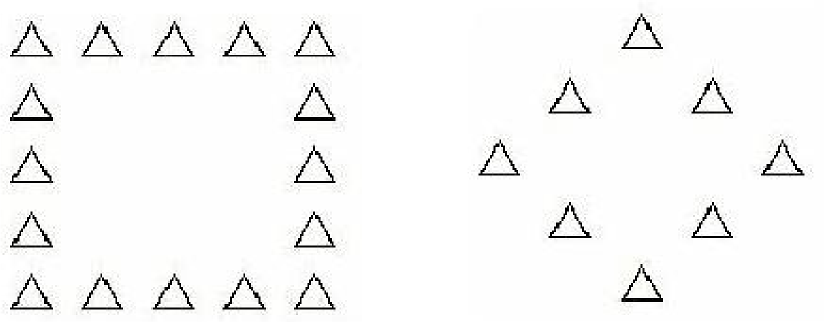

Figure 3. Distracter shapes for local condition.

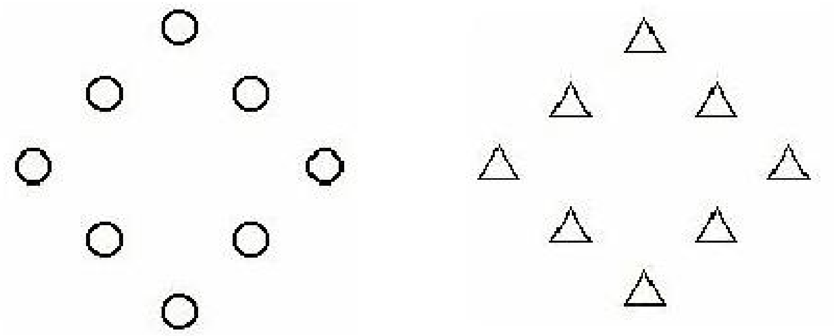

Figure 4. Distracter shapes for global condition.

Three different font sizes were used for each shape (12pt, 14pt and 16pt), meaning that global shapes varied in size (between 50mm X 70mm and 60mm X95mm). Both distracter and target shapes were presented in a random order with a target shape probability of p = 0.16 and distracter shape probability of p = 0.84. The stimuli were displayed for 100ms and then masked with an 85mm x 110mm black rectangle for 1000ms, during which the participants' response was recorded. Only responses made within this 1000ms period were recorded.

All participants were given a 4 minute trial period in order to familiarise themselves with the task. Following this 4 minute period participants undertook 14 two minute blocks which were completed consecutively. This resulted in the participant spending 32 minutes performing the task. Immediately following completion of the response task the

Near Infrared Spectroscopy was removed from the participants head, then immediately given the DSSQ post-task to complete. The Dundee Stress State Questionnaire (DSSQ; Appendix A) was used to assess the subjective state of participants. The DSSQ measures subjective state across four scales: Task-Related-Thoughts, Task-Unrelated-Thoughts, Energetic Arousal and Tense Arousal. The DSSQ was administered to the participants upon the completion of the experimental task. Following this they were debriefed about the experiment and its’ purpose, before receiving compensation for their time and leaving.

4. Results

4.1. Performance

As with studies of a similar nature (Helton et al, 2009), the overall rate of correct detections was high (*M* = 99.2%) while the false alarm rate remained low (*M* = 0.2%). This meant that mean reaction time was a more appropriate metric to use in data analysis. Mean reaction times of responses to target stimuli were calculated for each participant across each of the 14 vigil blocks in milliseconds (ms). Shapiro-Wilk tests for normality on the mean reaction times indicated deviation from normality, $p < .05$. Mean reaction times were therefore $\log_{10}$ transformed, as recommended by Maxwell and Delaney (2004). These transformed values were not deviant significantly from a normal distribution, $p > .05$. Response times of greater than 1000ms were not recorded.

One of the primary foci of the study was the vigilance decrement: the decline in performance quality with time spent on task. Performance quality in this case is determined by participants' reaction times. Previous laboratory research on the vigilance decrement has noted the possibility for an improvement in performance in periods of watch leading towards the end of the task (referred to as the end spurt effect; Bergum & Lehr, 1963). This can result in quadratic trends in laboratory vigilance research, with performance declining in the middle phases of the vigil task before returning to levels similar to those found at the start of the task. Therefore, the log reaction time scores were subjected to a 2 (condition: global versus local) X 14 (period of watch) ANOVA testing for specific linear and quadratic trends using orthogonal polynomial contrasts (Keppel & Zedeck, 2001). There was a non-significant (although approaching significance) linear trend for periods of watch, $F(1, 30) = 3.68$, $p = .07$, $\eta_p^2 = .11$, a significant quadratic trend for periods of watch, $F(1,30) = 7.88$, $p < .01$, $\eta_p^2 = .21$, a non-significant periods of watch by condition linear trend interaction, $F(1,30) = 1.39$, $p = .25$, and a significant periods of watch by condition quadratic trend, $F(1,30) = 4.03$, $p = .05$,

η_p^2 = .12 (see Figure 5). In order to further explore the interactions, we conducted separate analyses for the local and global conditions. In the local condition, there was no evidence of a linear trend for periods of watch, $F(1,15) = 0.47$, $p = .50$, but the quadratic trend was significant, $F(1,15) = 20.47$, $p < .01$, $\eta_p^2 = .58$. In the global condition, the linear trend, while statistically insignificant, was indicative, $F(1,15) = 3.37$, $p = .09$, $\eta_p^2 = .18$, but there was no evidence of a quadratic trend, $F(1,15) = 0.22$, $p = .64$.

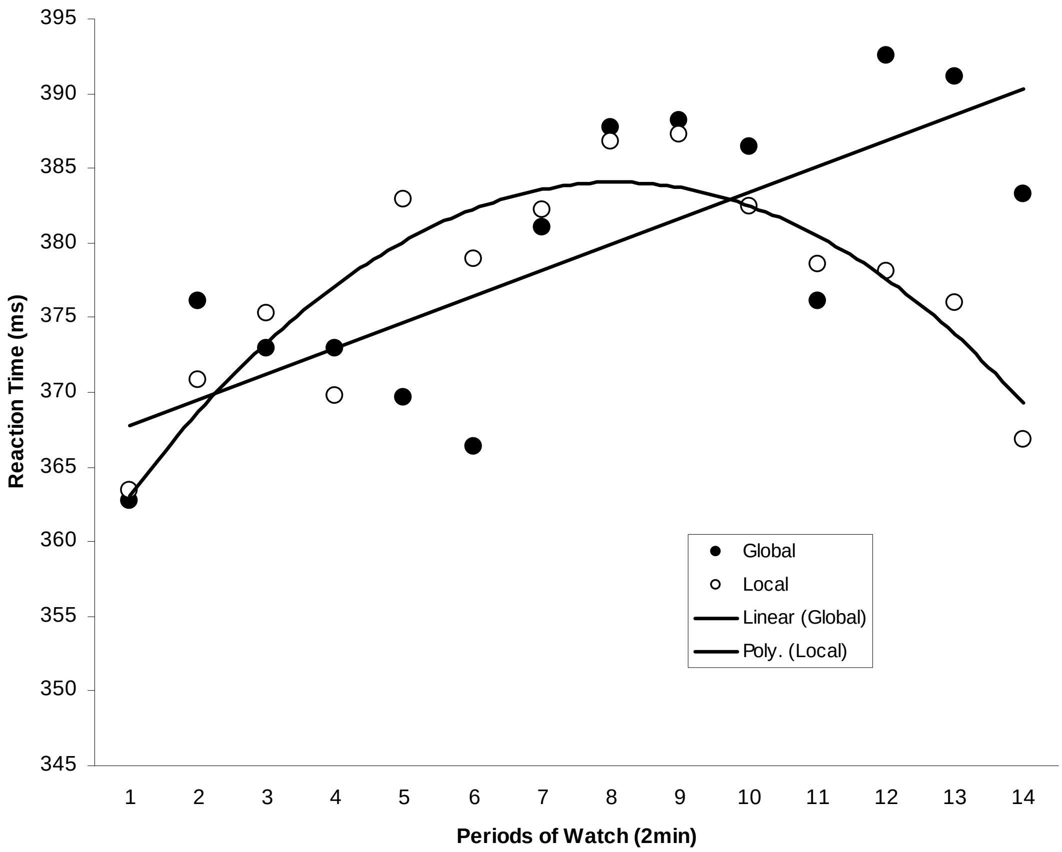

Figure 5. Mean target reaction time (ms) over the 14 2min periods of watch on the vigilance task.

4.2. Physiology

A relative measure of regional oxygen saturation (rSO_2) was used to assess the data gathered by the Near Infrared Spectroscopy, as has been utilized in previous studies of a similar nature (Yoshitani, Kawaguchi, Tatsumi, Kitaguchi and Furuya, 2002; Stevenson, Russell, & Helton, 2011). This involves measuring the percentage change in rSO_2 levels during the task relative to levels recorded before the task during the baseline period. A score of 0 indicates that there is no change in rSO_2 levels relative to the baseline. A positive difference in scores indicates an increase in rSO_2 levels while a negative difference indicates a decrease. A 2 (condition: global versus local) X 2 (hemisphere: right versus left) X 14 (period of watch) mixed-ANOVA was performed on the rSO_2 data. There was a significantly greater increase in rSO_2 levels in the right hemisphere (M = 3.13% SE = 0.51) than the left hemisphere (M = 1.05%, SE = 0.92), $F(1,30) = 5.48$, $p = .03$, $\eta_p^2 = .15$ and a significant period effect, $F(13, 390) = 2.67$, $p < .01$, $\eta_p^2 =.08$. There was also a significant group by period interaction, $F(13, 390) = 1.76$, $p = .05$, $\eta_p^2 =.06$ and a significant hemisphere by period interaction, $F(13, 390) = 2.87$, $p < .01$, $\eta_p^2 =.09$. The group by period interaction is displayed in Figure 6. In order to further explore these interactions, the hemispheres were analyzed separately with two 2 (group condition: global vs. local) x 14 (periods of watch) mixed-ANOVAs. For the right hemisphere, there was a significant periods effect, $F(13, 390) = 6.14$, $p < .01$, $\eta_p^2 =.17$, but no significant group effect or group by period interaction, $p > .05$. For the left hemisphere, there was a significant group by period interaction, $F(13, 390) = 2.24$, $p < .01$, $\eta_p^2 =.07$, but no significant group or period main effects, $p > .05$. Additional follow up tests were used to examine periods of watch effects for each group separately for each hemisphere. For the global condition, there was a significant periods of watch effect for the right hemisphere, $F(13, 195) = 2.78$, $p = .01$, $\eta_p^2 =.13$ (and indeed a significant linear trend, $F(1, 15) = 4.66$, $p = .05$, $\eta_p^2 =.24$), but not for the left hemisphere, $F(13, 195) = 0.86$, $p = .60$ (linear trend, $F(1, 15) = 0.72$, $p = .41$). For the local condition, there was a significant periods of watch effect for both the right hemisphere, $F(13, 195) = 4.45$, $p < .01$, $\eta_p^2 =.23$ (linear trend, $F(1, 15) = 7.70$, $p = .01$, $\eta_p^2 =.34$), and the left hemisphere, $F(13, 195) = 3.07$, $p < .01$,

η_p^2 =.17 (linear trend, $F(1, 15) = 4.55$, $p = .05$, η_p^2 =.23). These results can be seen in Figure 7.

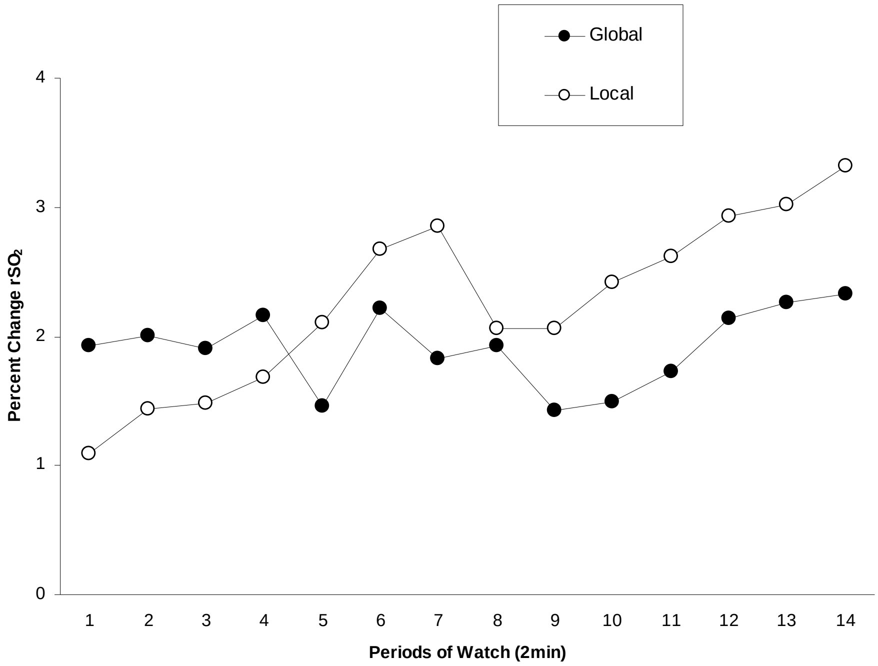

Figure 6. Mean oxygenation scores collapsed across hemispheres over the periods of watch for the global and local tasks. Oxygenation scores are based upon percent change relative to baseline.

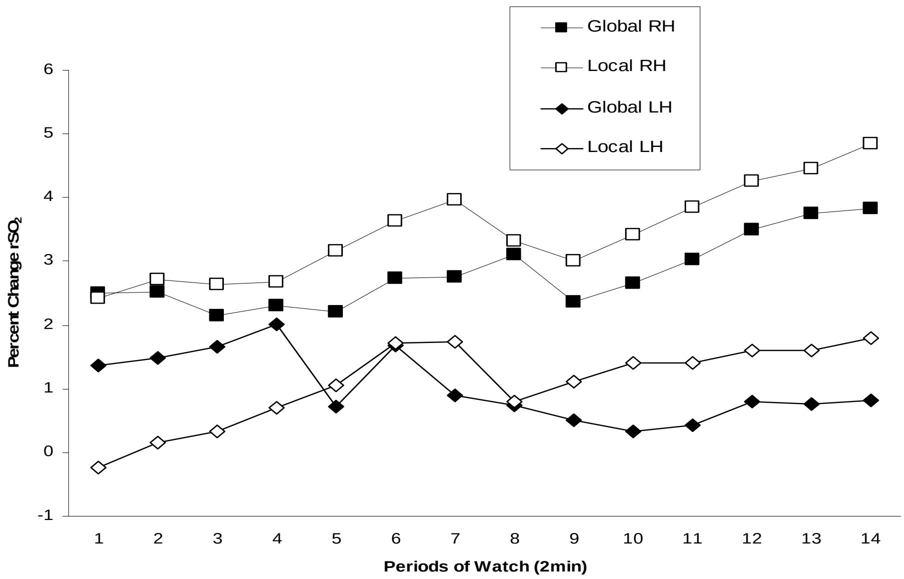

Figure 7. Mean oxygenation scores for the left hemisphere (LH) and the right hemisphere (RH) over the periods of watch by task type. Oxygenation scores are based upon percent change relative to baseline.

4.3. Subjective Self-Reports

All items on the DSSQ are measured on the same scale therefore the un-standardised scores were used in analysis. The items in these scales were averaged for each participant. The means are displayed in Figure 8. The subjective post-task report scales, Energetic Arousal, Tense Arousal, Task-Related Thoughts and Task Unrelated Thoughts, were compared using two tailed t-tests. There was a significant difference in Tense Arousal between the two groups, $t(30) = 2.09$, $p = .05$, $d = .76$, and trend towards a difference in Task Unrelated Thoughts, $t(30) = 1.96$, $p = .06$, $d = .72$. For both Energetic Arousal and Task-Related Thoughts the differences were insignificant, $t(30) < 1$, $p > .05$.

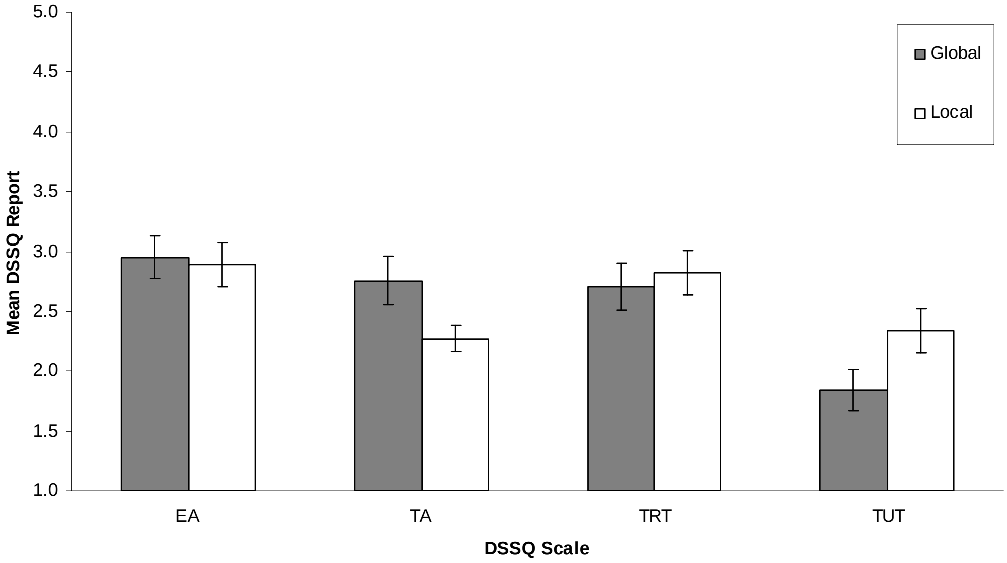

Figure 8. Mean DSSQ scores for Energetic Arousal (EA), Tense Arousal (TA), Task-Related Thoughts (TRT) and Task-Unrelated Thoughts (TUT) for the two tasks. Errors bars are standard errors of the mean.

5. Discussion

5.1. General Discussion

Hypotheses 1 and 2 were supported by our findings with the fNIRS data. Overall oxygenation levels were greater in the right hemisphere than in the left in both tasks. Right hemisphere oxygenation was also shown to increase with task duration. This suggests the right hemisphere is more dominant in vigilance tasks, which is in accordance to previous research in this area (Helton et al., 2007; Hitchcock et al., 2003; Parasuraman, Warm & See, 1998). Global and local feature conditions exhibited similar right hemisphere oxygenation patterns, however in the global condition left hemisphere oxygenation declined with task duration, while in the local condition left hemisphere oxygenation was found to increase with task duration. This could be an indication that the local discrimination task produces a greater increase in bilateral hemisphere activation and coordination over time in comparison to that produced in the global discrimination task.

Hypothesis 3 was partially supported by performance data. Reaction time in the local feature discrimination task displayed a quadratic trend, with reaction times increasing during the middle of the task before returning to the initial levels found at the beginning of the task. The global feature discrimination task did not display this trend, and instead demonstrated a possible linear trend with reaction times increasing throughout the duration of the task. Hypothesis 3 predicted that reaction times in the local discrimination condition would be faster than those in the global discrimination condition. While reaction times at the end of the task are indeed faster in the local condition, the quadratic trend which the local condition reactions times display means that throughout the middle stages of the task the global condition reaction times were faster. It would not be appropriate to suggest that hypothesis 3 was completely supported by the data, and may require further investigation. Hypothesis 4 stated that vigilance decrement would occur as time-on-task increased. The linear trend found in the global condition supports this hypothesis. It can also be said that the local condition reaction times support this hypothesis, as despite the quadratic trend shown, the reaction times are for the most part increasing before the end spurt effect.

Hypothesis 5 states that we expected there would be significant differences between conditions in regards to the self-reported subjective state resulting from the tasks. This hypothesis is supported by the DSSQ results. Participants did report less tense arousal in the local than the global task condition, and there was a trend for more task-unrelated thoughts in the local than the global task condition. Both of these suggest participants did notice the results of the increased bilateral activation in the local task condition (though not necissarly awarenss of the bilateral activity itself).

Sustained attention is right hemisphere lateralized while local-feature discrimination is left hemisphere lateralized, which led to the prediction that the resulting bilateral cerebral activity would lead to improved performance in the local feature condition relative to the global feature condition. The global feature discrimination task results in the processing load not being shared efficiently between the left and right hemispheres. Instead, the right hemisphere is required to take on the majority of the processing load, which in turn leads to impaired performance in the global feature discrimination condition relative to the local feature discrimination condition. Due to the targets being identical in each condition and the distracter targets being different, the differences found in performance data cannot be attributed to any properties of the targets themselves. The initial response times were identical for each condition, further illustrating this point. When we take this into consideration with the quadratic trend exhibited in the reaction times of local discrimination task participants, specifically the improvement in performance towards the end of the task, the data suggests that increases in bilateral engagement due to local-feature discriminations may enhance vigilance performance over time.

The Helton et al (2009) study found a difference in bilateral activation between difficult and easy vigilance tasks, specifically with difficult tasks exhibiting an increase in bilateral activation relative to easier tasks. It is therefore possible that a difference in difficulty of the conditions is influencing the fNIRS findings. There are a couple of reasons to suggest that this is not the case in the current research however. Firstly it was found in the performance data that initial reaction times were identical between the two conditions. This initial similarity suggests that participants did not find the tasks significantly different in terms of difficulty. Both conditions also showed a high level of correct detections and low levels of false alarms, indicating that the tasks overall were not challenging in comparison to other vigilance tasks used previously in vigilance research. Secondly, the DSSQ which was employed pre- and post-task measured mood changes and thought occurrences during the task. It is generally found that reports of task-unrelated thoughts increases during unchallenging tasks (Smallwood et al., 2003). The self reports gathered here show a trend for task-unrelated thoughts being higher in the local discrimination condition than in the global discrimination condition. Participants in the global discrimination condition also reported higher levels of post-task tense arousal than those in the local discrimination condition. The findings suggest that participants in the local condition were less aroused and had more time to daydream than those in the global condition. This may mean that the local discrimination condition was subjectively less challenging to participants than the global discrimination condition. These findings are therefore inconsistent with an argument suggesting target difficulty is a factor.

5.2. Real World Implications

There are many real world settings where individuals are required to engage in either local feature or global feature discriminations. There are also many settings in which individuals may be required to engage in both simultaneously, or rapidly changing between the two. The findings of the current study may therefore have some impact on individuals in the real world.

The field in which local and global feature discrimination is likely to have the greatest impact is in computer displays and user-interface design. This is due to the greater degree of control that the designer has in relation to the construction of these displays and the objects used in them. If a designer was to use objects which were biased towards one particular type of object discrimination, this dominance of object discrimination could in turn impact upon other tasks which that display or interface is used for by an operator. For example, if a display was dominated by objects which required global feature discrimination this could over time result in similar effects on performance and physiology as found in the current study. If the user of such a display was asked to simultaneously complete a task which placed additional load on the right hemisphere, the effects on performance and physiology could be exasperated further. This could result in decreased performance levels in both the discrimination task and the additional task required. This could have detrimental effects in settings where these screen displays are used, both in the workplace as well as in private.

The same principles may also apply to the layout of workbenches or control panels. Control panels may range from relatively simple designs with a small number of buttons (for example, the front panel of a car) to quite complex designs consisting of hundreds of a buttons and objects with different functions (for example, an airplane cockpit). In an emergency situation involving a complex control panel, the operator may be required to activate a specific button to initiate a required function. If the operator does not have intimate knowledge of the exact layout of the control panel, this search for a unique button may then resemble a vigilance task. In the case of airplane operation, one could argue that the pilot is in a constant sustained attention task to begin with, much like driving a car. This means that when the time is required to begin this search they may be displaying the effects of vigilance decrement to begin with. Therefore, if their performance is already at a reduced level of quality, the nature of the target and the feature discrimination required could impact on the reaction times. While the pilot would most likely activate the right button (again, correct detections were near flawless in the current research), the difference in reaction times could factor in to how quickly the operator regains control of the situation. This could be the difference between a near-miss and an accident. Again, the designers of such systems, displays and interfaces should factor in the effect that biases towards one specific type of feature discrimination may have.

Two common road signs used on roads around the world are the stop and the give way signs. These signs are set up in a way which requires a driver to engage in either local or global feature discrimination. The stop sign consists of the word stop in capital letters, the local features, within a large red octagon, the global features. The give way sign consists of the words give way in capital letters (local features) within an inverted triangle (global feature). An individual who approaches either of these signs is required to process either of these features and act accordingly. Should either the global or local features be obscured in any way, it is intended that the driver is still able to determine what the sign is and what action to take. Therefore local and global discriminations are important for warning signage, road related as well as workplace related. In situations where an operator may encounter a number of warning signs within quick succession or is mentally fatigued (at the low end of the vigilance decrement), the local features of these warning signs may assist with quicker processing of the information that the operator needs to know, thus resulting in slightly quicker reaction times allowing the operator to react to that situation in a faster manner. This of course does not take into account various competing real world factors such as the association of certain shapes and colours to certain actions (such as red relating to “no-go zones" in some workplaces), however local and global features may still play a role in these situations.

A common saying used to describe a situation where someone appears to be focussed on the smaller details of something is "cannot see the forest for the trees". In a way, this could be related to situations involving the discrimination of local and global features. An individual may be intensely focussed on the local features that they neglect the global features. The reverse of this situation may also occur. This is likely to be detrimental to performance in most workplaces. Therefore it may be appropriate to set up workplaces in such a way that it avoids the total dependence on one particular type of feature discrimination. This is much easier in some situations than others. The design of computer displays and the layout of control panels are areas where designers have greater control over the type of object discriminations required of the user. It is these areas where the findings of the currently study may best be utilized. Where this is not possible, it may be appropriate to train workers in ways to avoid focussing on solely local or solely global features. This idea is discussed in future research directions (section 5.4.)

5.3. Limitations

One possible limitation with the current research is the sample size. Due to time and resource constraints it was not possible to conduct this experiment with a large number of participants. Perhaps given a larger sample size the trends found in the data could be examined with more clarity. The research did however yield strong results which were consistent with the previous Helton et al (2009) study, suggesting that this is not a large limitation of the study. More of a limitation in the sample may be that the majority of participants in the sample size were male. It is possible that sex differences can influence the subjective reports of stress (Ossowski, Malinen & Helton, 2011). Emotional expression has been found to be one of the areas where gender differences are most distinct (Kring & Gordon, 1998). Therefore, sampling more females in this experiment may provide differing and more representative DSSQ (self) reports.

It has been found that stressful experiences can have strong connections to emotions, and this subsequent emotional state can be influential on how individuals react in these stressful situations. Research has found that emotional state has an influence in very early stages of cognitive processing (Niedenthal, Halberstadt & Setterlund, 1997). Therefore, it is possible that emotional state could be extremely influential on an individual's performance in vigilance tasks (Helton & Russell, 2011). The current study did not examine participants' emotional state prior to undertaking the experiment, nor did it attempt to control for emotional state. This could be seen as both a limitation as well as an area for future research, especially considering that emotional processing is itself right hemisphere dominate and this may add additional burdens during vigilance (Helton, Dorhay, & Russell, 2011). Further illustrating the need for more females in the sample, research has previously found that there are neurobiological differences between males and females in the way that each processes emotions (Lithari et al., 2010). This indicates that as well as differing DSSQ scores, an increase in females in the sample may result in changes to performance scores throughout the task.

The final limitation of the current research is the possibility of screen clutter during the task duration. The stimuli used were placed in the centre of the screen, with a large amount of blank space surrounding the object. It is possible that this resulted in the object appearing compressed to the participant, making the act of distinguishing between local and global features more difficult. One potential way around this limitation would be to simply increase the size of the stimuli used. Doing this would hopefully result in decreasing the possibility of participants experiencing screen clutter. If this were attempted, care would needed to be taken so that the objects were not resized to be of too great in size, resulting in the local features being too large to have participants effectively engage in feature discrimination.

5.4. Future Research Directions

Despite the findings of the current research, there is a need for a greater amount of research in regards to how global versus local feature discrimination interacts with sustained attention tasks and how this affects the vigilance decrement. One major issue is that prior research has found a global precedence effect. This means that in real world settings global objects appear to have greater salience than local objects. The findings in the current study, as well as the study by Helton et al. (2009) which this research is an extension of, appear to be in contrast to this. Further research is needed to investigate the generalization of these results to real world situations.

The stimuli used in this research appear to render the local information redundant (the same local features are used in the global figure). In real world settings it is likely that people would be required to negotiate a much wider range of local features forming the global figure. For example, the target stimulus used in this research was a square comprised of smaller circles. If the target stimulus was instead a square comprised of a range of smaller shapes (squares, diamonds, triangles), with one small circle, we would expect that this task would pose much greater difficulty to those in the local condition than in the global condition. Could designers of displays and interfaces find ways to give local objects a similar level of salience to global objects (for example, using colour, movement, or onset-offsets “flashing”)? The overall characteristics of the objects used may play an important role in how feature discrimination affects performance. If local features can be made more salient, this may improve detection performance, especially with time on task.

The majority of the vigilance literature referred to in this study uses relatively easy global-based discriminations, which activate the right hemisphere. Difficult local-based discrimination tasks in contrast may result in increased bilateral activation. This in turn has implications to real world settings, as the target stimuli we are required to detect in everyday situations is rarely as basic as laboratory setting stimuli. Hemisphere dominance in vigilance tasks needs to be investigated further, controlling for both task difficulty, shown in Helton et al. (2010), and nature of discrimination, shown in Helton et al. 2009 and in the current study.

Following on from examples given in real world implications, it is relatively rare that an individual will be required to undertake solely local or solely global discrimination in a vigilance type task. Although not examined in the current study, cerebral activation during tasks which require changing between global and local discrimination could be investigated in future research. This may further allow us to examine patterns of cerebral activation during sustained attention tasks. It would also allow for researchers to make more accurate inferences on how global and local discrimination influences real world behaviours during sustained attention.

6. References

Aaslid, R. (1986). Transcranial Doppler examination techniques. In R. Aaslid (Ed.), *Transcranial Doppler sonography* (pp. 39–59). New York: Springer-Verlag.

Arnold, H. J., & Feldman, D. C. (1981). Social desirability response bias in self-report choice situations. *Academy of Management Journal*, 377-385.

Ballard, J.C., (1996). Computerized assessment of sustained attention: A review of factors affecting vigilance performance. Journal of Clinical and Experimental Neuropsychology, 18, 843-863.

Bergum, B.O. & Lehr, D.J. (1963). End spurt in vigilance. *Journal of Experimental Psychology, 66,* 383-385.

Berman, K.F., & Weinberger, D.R. (1990). Lateralization of cortical function during cognitive tasks: Regional cerebral blood flow studies of normal individuals and patients with schizophrenia. *Journal of Neurology, Neurosurgery, and Psychiatry, 53*, 150-160.

Biebuyck, J. F., Weinger, M. B., & Englund, C. E. (1990). Ergonomic and human factors affecting anesthetic vigilance and monitoring performance in the operating room environment. *Anesthesiology, 73*(5), 995.

Buchsbaum, M.S., Nuechterlein, KI.H., Haier, R.J., Wu, J., Sicotte, N., Hazlett, E., Asarnow, R. Potkin, S., Guich, S. (1990). Glucose metabolic rate in normals and schizophrenics during the continuous performance test assessed by positron emission tomography. *British Journal of Psychiatry, 156*, 216-227.

Damos, D.L., & Parker, E.S (1994). High false alarm rates on a vigilance task may indicate recreational drug use. *Journal of Clinical and Experimental Neuropsychology, 16,* 713-722.

Davies, D.R., & Parasuraman, R. (1982). *The psychology of vigilance.* London: Academic Press.

Diamond, S.J. (1979). Performance by split-brain humans on lateralized vigilance tasks. *Cortex, 15,* 43-50.

Diamond, S.J. (1979). Tactual and auditory vigilance in spilt-brain man. *Journal of Neurology, Neurosurgery, and Psychiatry, 42,* 70-74.

Ekkekakis, P. (2009). Illuminating the black box: Investigating prefrontal cortical hemodynamics during exercise with near-infrared spectroscopy. *Journal of Sport and Exercise Psychology, 31,* 505-553.

Fink, G. R., Halligan, P. W., Marshall, J. C., Frith, C. D., Frackowiak, R. S., & Dolan, R. J. (1997). Neural mechanisms involved in the processing of global and local aspects of hierarchically organized visual stimuli. *Brain, 120*(10), 1779-1791.

Fink, G. R., Marshall, J. C., Halligan, P. W., Frith, C. D., Frackowiak, R. S. J., & Dolan, R. J. (1997). Hemispheric specialization for global and local processing: the effect of stimulus category. *Proceedings of the Royal Society of London. Series B: Biological Sciences, 264*(1381), 487-494.

Flevaris, A. V., Bentin, S., & Robertson, L. C. (2010). Local or Global? *Psychological Science, 21*(3), 424.

Flevaris, A. V., Bentin, S., & Robertson, L. C. (2011). Attention to hierarchical level influences attentional selection of spatial scale. *Journal of Experimental Psychology: Human Perception and Performance, 37*(1), 12.

Flevaris, A. V., Bentin, S., & Robertson, L. C. (2011). Attentional selection of relative SF mediates global versus local processing: Evidence from EEG. *Journal of Vision, 11*(7).

Frankenhaeuser, M., Nordheden, B., Myrsten, A. L., & Post, B. (1971). Psychophysiological reactions to understimulation and overstimulation. *Acta Psychologica*, *35*(4), 298-308.

Galinsky, T. L., Rosa, R. R., Warm, J. S., & Dember, W. N. (1993). Psychophysical determinants of stress in sustained attention. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 35*(4), 603-614.

Giambra, L.M. (1995) A laboratory based method for investigating influences on switching attention to task unrelated imagery and thought. *Consciousness and Cognition, 4,* 1-21.

Gratton, G., & Fabiani, M. (2007). Optical imaging of brain function. In R. Parasuraman & M. Rizzo (Eds.), *Neuroergonomics:The brain at work (*pp. 65-81). New York: Oxford.

Hancock, P. A., & Hart, S. G. (2002). Defeating terrorism: What can human factors/ergonomics offer? *Ergonomics and Design*, *10*, 6–16.

Hancock, P. A., & Warm, J. S. (1989). A dynamic model of stress and sustained attention. *Human Factors*, *31*, 519–537.

Helton, W.S., Dorahy, M.J., & Russell, P.N. (2011). Dissociative tendencies and right hemisphere processing load: effects on vigilance performance. *Consciousness and Cognition, 20,* 696-702.

Helton, W.S., & Russell, P.N. (2011). The effects of arousing negative and neutral picture stimuli on target detection in a vigilance task. *Human Factors, 53,* 132-141.

Helton, W. S., & Russell, P. N. (2012). Brief mental breaks and content-free cues may not keep you focused. *Experimental Brain Research,* 1-10.

Helton, W.S. & Warm, J.S. (2008). Signal salience and the mindlessness theory of vigilance. *Acta Psychologica, 129,* 18-25.

Helton, W.S. (2010). The relationship between lateral differences in tympanic membrane temperature and behavioral impulsivity. *Brain and Cognition, 74, 75-78.*

Helton, W.S., Matthews, G., & Warm, J.S. (2009). Stress state mediation between environmental variables and performance: The case of noise and vigilance *Acta Psychologica, 130,* 204-213.

Helton, W.S., Dember, W.N., Warm, J.S., & Matthews, G. (2000) Optimism-pessimism and false failure feedback: effects on vigilance performance. *Current Psychology, 18,* 311-325.

Helton, W. S. (2004). *Validation of a short stress state questionnaire.* Paper presented at the Human Factors and Ergonomics Society 48th Annual Meeting.

Helton, W.S., Hollander, T.D., Warm, J.S., Matthews, G., Dember, W.N., Wallart, M., Beauchamp, G., Parasuraman, R., & Hancock, P.A. (2005). Signal regularity and the mindlessness model of vigilance. *British Journal of Psychology, 96,* 249-261. 39

Helton, W.S., Hollander, T.D., Tripp, L.D., Parsons, K., Warm, J.S., Matthews, G., & Dember, W.N. (2007). Cerebral hemodynamics and vigilance performance. *Journal of Clinical and Experimental Neuropsychology, 29,* 545-552.

Helton, W. S., Kern, R. P., & Walker, D. R. (2009). Conscious thought and the sustained attention to response task. *Consciousness and Cognition, 18*, 600-607.

Helton, W.S., Hayrynen, L., & Schaeffer, D. (2009). Sustained attention to local and global target features is different: Performance and tympanic membrane temperature. *Brain and Cognition, 71*, 9-13.

Helton, W.S., Shaw, T., Warm, J.S., Matthews, G., & Hancock, P.A. (2008). Effects of warned and unwarned demand transitions on vigilance performance and stress. *Anxiety, Stress and Coping, 21*, 173-184.

Hitchcock, E.M., Warm, J.S., Mathews, G., Dember, W.N., Shear, P.K., Tripp, L.D., Mayleben, D.W., & Parasuraman, R. (2003). Automation cueing modulates cerebral blood flow and vigilance in a simulated air traffic control task. *Theoretical Issues in Ergonomics Science, 4,* 89-112.

Hovanitz, C. A., Chin, K., & Warm, J. S. (1989). Complexities in life stress-dysfunction relationships: A case in point—tension headache. *Journal of behavioral medicine, 12*(1), 55-75.

Ishii, Y., Ogata, H., Takano, H., Ohnishi, H., Mukai, T., Yagi, T. (2008). Study on mental stress using near-infrared spectroscopy, electroencephalography, and peripheral arterial tonometry. *Engineering in Medicine and Biology Society, 2008. EMBS 2008. 30th Annual International Conference of the IEEE* , pp.4992-4995.

See, J. E., Howe, S. R., Warm, J. S., & Dember, W. N. (1995). Meta-analysis of the sensitivity decrement in vigilance. *Psychological Bulletin, 117*(2), 230.

Brache, K., Scialfa, C., & Hudson, C. (2010). Aging and vigilance: who has the inhibition deficit? Experimental Aging Research, 36, 140-152.

Kahneman, D. (1973). *Attention and effort.* Englewood, NJ: Prentice Hall. 40

Keppel, G. & Zedeck, S. (2001). *Data analysis for research designs.* New York: W.H. Freeman & Co.

Kimichi, R. (1992). Primacy of holistic processing and global/local paradigm: a critical review. *Psychological Bulletin, 112,* 24-38.

Kinsbourne, M. (1982). Hemispheric specialization and the growth of human understanding. *American Psychologist, 37,* 411-420.

Kirilina, E., Jelzow, A., Heine, A., Niessing, M., Wabnitz, H., Brühl, R., Ittermann, B., Jacobs, A., & Tachtsidis, I. (2012). The physiological origin of task-evoked systemic artefacts in functional near infrared spectroscopy, *NeuroImage, Volume 61, Issue 1,* 70-81

Kring, A. M. & Gordon, A. H. (1998). Sex differences in emotion: Expression, experience and physiology. *Journal of Personality and Social Psychology, 74,* 686 – 703.

Lamb, M.R., & Robertson, L.C. (1990). The effect of visual angle on global and local reaction times depends on the set of visual angles presented. *Perception & Psychophysics, 47,* 489-496.

Lithari, C., Frantzidis, C. A., Papadelis, C., Vivas, A. B., Klados, M. A., Kourtidou-Papadeli, C., & et al. (2010). Are females more responsive to emotional stimuli? A neurophysiological study across arousal and valence. *Brain Topography, 23,* 27-40.

Lundberg, U. (2005). Stress hormones in health and illness: The roles of work and gender. *Psychoneuroendocrinology, 30,* 1017–1021.

Lux, S., Marshall, J.C., Ritzl, A., Weiss, P.H., Pietrzyk, U., Shah, N.J., Zilles, K., & Fink, G.R. (2004). A functional magnetic resonance imaging study of local/global processing with stimulus presentation in the peripheral visual hemifields. *Neuroscience*, *124*,113-120.

Mackworth, N.H. (1948). The breakdown of vigilance during prolonged visual search. *Quarterly Journal of Experimental Psychology, 1*, 6-21.

MacLean, K.A., Aichele, S.R., Bridwell, D.A., Mangun, G.R., Wojciulik, E., & Saron, C.D. (2009). Interactions between endogenous and exogenous attention during vigilance. *Attention, Perception, & Psychophysics, 71*, 1042–1058.

Manly, T., Robertson, I.H., Galloway, M., & Hawkins, K. (1999). The absent mind: Further investigations of sustained attention to response. *Neuropsychologia*, *37,* 661-670.

Matthews, G., Joyner, L., Gilliland, K., Huggins, J., & Falconer, S. (1999). Validation of a comprehensive stress state questionnaire: Towards a state big three? In I. Merville, I.J. Deary, F. DeFruyt, and F. Ostendorf (Eds.), *Personality psychology in Europe* (vol. 7) (pp. 335-350). Tilburg: Tilburg University Press. 41

Matthews, G., Campbell, S.E., Falconer, S., Joyner, L.A., Huggins, J., Gilliand, K., Grier, R., & Warm, J.S. (2002). Fundamental dimensions of subjective state in performance settings: Task engagement, distress, and worry. *Emotion*, *2,* 315-340.

Matthews, G., Warm, J. S., Dember, W. N., Mizoguchi, H. & Smith. A. P. (2001). The common cold impairs visual attention, psychomotor performance and task engagement. In *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting* (pp. 1377-1381). Santa Monica. CA: Human factors and Ergonomics Society.

Maxwell, S. E., & Delaney, H. D. (2004). *Designing experiments and analyzing data: A model comparison perspective* (Vol. 1): Lawrence Erlbaum.

Navon, D. (1977). Forest before the trees: the precedence of global features in visual perception. *Cognitive Psychology, 9,* 353-383.

Niedenthal, P. M., Halberstadt, J. B., & Setterlund, M. B. (1997). Being happy and seeing “happy”: Emotional state facilitates visual encoding. *Cognition and Emotion, 11*, 403–432.

Oken, B. S., Salinsky, M. C., & Elsas, S. M. (2006). Vigilance, alertness, or sustained attention: physiological basis and measurement. *Clinical Neurophysiology, 117*(9), 1885-1901.

Ossowski, U., Malinen, S., & Helton, W.S. (2011). The effects of emotional stimuli on target detection: indirect and direct resource costs. *Consciousness and Cognition, 20*, 1649–1658.

Parasuraman, R., Warm, J. S., & See, J. E. (1998). Brain systems of vigilance. In R. Parasuraman (Ed.), *The attentive brain* (pp. 221–256). Cambridge, MA: MIT Press.

Plichta, M., Gerdes, A., Alpers, G., Harnisch, W., Brill, S., Wieser, M., & Fallgatter, A. (2011). Auditory cortex activation is modulated by emotion: A functional near-infrared spectroscopy (fNIRS) study. *NeuroImage, Volume 55, Issue 3,* 1200-1207

Podsakoff, P. M., & Organ, D. W. (1986). Self-reports in organizational research: Problems and prospects. *Journal of Management, 12*(4), 531-544.

Posner, M.I., & Peterson, S.E. (1990). The attention system of the human brain. *Annual Reviews of Neuroscience, 13,* 25-42.

Rahnuma, K.S., Wahab, A., Kamaruddin, N., Majid, H. (2011). EEG analysis for understanding stress based on affective model basis function. *IEEE 15th International Symposium on Consumer Electronics (ISCE),* pp.592-597.

Richman, W. L., Kiesler, S., Weisband, S., & Drasgow, F. (1999). A meta-analytic study of social desirability distortion in computer-administered questionnaires, traditional questionnaires, and interviews. *Journal of Applied Psychology, 84*(5), 754.

Robertson, I.H., Manly, T., Andrade, J., Baddeley, B.T., & Yiend, J. (1997). "Oops!": Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia, 35,* 747-758.

Scerbo, M. (1998). What's so boring about vigilance? In R.B. Hoffman, M.F. Sherrick, & J.S. Warm (Eds.), *Viewing psychology as a whole: The integrative science of William N. Dember* (pp. 145-166). Washington, DC: APA.

Shaw, T.H., Warm, J.S., Finomore, V., Tripp, L., Matthews, G., Weiler, E., & Parasuraman, R. (2009). Effects of sensory modality on cerebral blood flow velocity during vigilance. *Neuroscience Letters 461,* 207-211.

Smallwood, J. (2010). Why the global availability of mind wadering necessitates resource competition: Reply to McVay and Kane (2010). *Psychological Bulletin, 136,* 202-207.

Stevenson, H., Russell, P.N., & Helton, W.S. (2011). Search asymmetry, sustained attention, and response inhibition. *Brain and Cognition, 77,* 215-222.

Stroobant, N. & Vingerhoets, G. (2000) Transcranial doppler ultrasonography monitoring of cerebral hemodynamics during performance of cognitive tasks: A review. *Neuropsychology Review, 10,* 213-231.

Szalma, J.L., Hancock, P.A., Dember, W.N., & Warm, J.S. (2006). Training for vigilance: The effect of knowledge of results format and dispositional optimism and pessimism on performance and stress. *British Journal of Psychology, 97,* 115-135.

Szalma, J. L.,Warm, J. S., Matthews, G., Dember,W. N.,Wiler, E. M., Meier, A., & Eggemeier, (2004). Effects of sensory modality and task duration on performance, workload, and stress in sustained attention. *Human Factors, 46,* 219–233.

Tanida, M., Katsuyama, M., & Sakatani, K. (2007). Relation between mental stress-induced prefrontal cortex activity and skin conditions: A near-infrared spectroscopy study. *Brain Research, 1184*, 210-216

Temple, J.G., Warm, J.S., Dember, W.N., Jones, K.S., LaGrange, C.M., & Matthews, G. (2000) The effects of signal salience and caffeine on performance, workload and stress in an abbreviated vigilance task. *Human Factors, 42,* 183-194.

Toronov, V., Webb, A., Choi, J. H., Wolf, M., Michalos, A., Gratton, E., et al. (2001). Investigation of human brain hemodynamics by simultaneous near-infrared spectroscopy and functional magnetic resonance imaging. *Medical Physics, 28,* 521–527.

Wang, J., Rao, H., Wetmore, G. S., Furlan, P. M., Korczykowski, M., Dinges, D. F., et al. (2005). Perfusion functional MRI reveals cerebral blood flow pattern under psychological stress. *Proceedings of the National Academy of Sciences of the United States of America, 102*(49), 17804.Warm, 1993

Warm, J.S., Matthews, G., & Parasuraman, R. (2009). Cerebral hemodynamics and vigilance performance. *Military Psychology. 21, (Supplement 1),* S75-S100

Warm, J.S., Parasuraman, R., & Matthews, G. (2008). Vigilance requires hard mental work and is stressful. *Human Factors, 50*, 433-441.

Hollands, J. G., & Wickens, C. D. (1999). *Engineering psychology and human performance*: Prentice Hall New Jersey.

Wilkinson, R. (1969). Some factors influencing the effect of environmental stressors upon performance. *Psychological Bulletin, 72*(4), 260.

Yamaguchi S., Yamagata S., & Kobayashi, S. (2000). Cerebral asymmetry of the “top-down” allocation of attention to global and local features. *Journal of Neuroscience, 20,* 1–5.

Yoshitani, K., Kawaguchi, M., Tatsumi, K., Kitaguchi, K., & Furuya, H. (2002). A comparison of the INVOS 4100 and the NIRO 300 near-infrared spectrophotometers. *Anthesia & Analgesia, 94,* 586-590.

Appendix A – Dundee Stress State Questionnaire

DSSQ QUESTIONNAIRE

General Instructions. This questionnaire is concerned with your feelings and thoughts during the task. Please answer **every** question, even if you find it difficult. Answer, as honestly as you can, what is true of **you**. Your answers will be kept entirely confidential. You should try and work quite quickly. The first answer you think of is usually the best.

Please indicate how well each word describes how you felt **DURING THE TASK** (circle the answer from 1 to 5).

Not at all = 1 A little bit = 2 Somewhat = 3 Very much = 4 Extremely = 5

1. Energetic	1	2	3	4	5
2. Relaxed	1	2	3	4	5
3. Alert	1	2	3	4	5
4. Nervous	1	2	3	4	5
5. Passive	1	2	3	4	5
6. Tense	1	2	3	4	5
7. Jittery	1	2	3	4	5
8. Sluggish	1	2	3	4	5
9. Composed	1	2	3	4	5
10. Restful	1	2	3	4	5
11. Vigorous	1	2	3	4	5
12. Anxious	1	2	3	4	5
13. Unenterprising	1	2	3	4	5
14. Calm	1	2	3	4	5
15. Active	1	2	3	4	5
16. Tired	1	2	3	4	5

Please indicate roughly how often you had each thought **DURING THE TASK.**

Never = 1 Once = 2 A few times = 3 Often = 4 Very often = 5

17.	I thought about how I should work more carefully.	1	2	3	4	5
18.	I thought about how much time I had left.	1	2	3	4	5
19.	I thought about how others have done on this task.	1	2	3	4	5
20.	I thought about the difficulty of the problems.	1	2	3	4	5
21.	I thought about my level of ability.	1	2	3	4	5
22.	I thought about the purpose of the experiment.	1	2	3	4	5
23.	I thought about how I would feel if I were told how I performed.	1	2	3	4	5
24.	I thought about how often I get confused.	1	2	3	4	5
25.	I thought about members of my family.	1	2	3	4	5
26.	I thought about something that made me feel guilty.	1	2	3	4	5
27.	I thought about personal worries.	1	2	3	4	5
28.	I thought about something that made me feel angry.	1	2	3	4	5
29.	I thought about something that happened earlier today.	1	2	3	4	5
30.	I thought about something that happened in the recent past (last few days, but not today).	1	2	3	4	5
31.	I thought about something that happened in the distant past	1	2	3	4	5
32.	I thought about something that might happen in the future.	1	2	3	4	5

Appendix B – Information Sheet, Consent Form and Debriefing Sheet

University of Canterbury

Department of Psychology

INFORMATION

You are invited to participate as a subject in the research project *A Functional Near-Infrared Spectroscopy Study of Sustained Attention to Local and Global Target Features*.

The aims of this project are:

1. To examine the effects that object features have on an individual's task performance.
2. To examine cerebral oxygenation patterns throughout the duration of the task.
3. Whether subjective state assessments correlate with performance indicators during the task.

You have the right to withdraw from the project at any time, including withdrawal of any information provided.

This research utilizes a technique called a functional Near-Infrared Spectroscopy (fNIRS). It is a non-invasive and painless technique which uses two sensor pads placed on the forehead to measure blood oxygenation levels. You will be shown how the fNIRS operates before the task, and will be given an opportunity to become accustomed to the fNIRS before deciding whether you would like to continue. If at any time you feel uncomfortable with the fNIRS you have the right to stop the experiment.

The results of the project may be published, but you may be assured of the complete confidentiality of data gathered in this investigation: the identity of participants will not be made public without their consent. To ensure anonymity and confidentiality, you will be assigned a unique numerical code for the purposes of the study. Any personally identifying information will be kept separate from this code. The data will be kept in a locked cabinet in a locked room in a locked building. The project is being carried out *as* a requirement for course by **Neil de Joux** under the supervision of Dr. Deak Helton, who can be contacted at +64 3 364 2998, ext. 7999. He will be pleased to discuss any concerns you may have about participation in the project. All parts of this project have been reviewed and approved by the University of Canterbury Human Ethics Committee.

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

CONSENT FORM

A Functional Near-Infrared Spectroscopy Study of Sustained Attention to Local and Global Target Features.

I have read and understood the description of the above-named project. On this basis I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved.

I understand also that I may at any time withdraw from the project, including withdrawal of any information I have provided. Withdrawal of participation will not result in course credit withdrawal for PSYC105/106 participants.

I note that the project has been reviewed by the University of Canterbury Human Ethics Committee.

NAME (please print): ……………………………………………………………….

Signature:

Date:

Debriefing Sheet

A Functional Near-Infrared Spectroscopy Study of Sustained Attention to Local and Global Target Features.

The current research investigates the effects of target characteristics on the vigilance decrement. The vigilance decrement occurs when performance on tasks requiring sustained attention decreases over time. The target characteristics refer to the objects presented in the study.

Both conditions were to respond to the square composed from smaller circles. However the distracter objects in the conditions differed, with one condition being required to look at the local features of the object (the circles) and one condition being required to look at the global features of the object (the square).

Functional Near-Infrared Spectroscopy (fNIRS) is being used to establish whether cerebral activity differs between conditions. Local tasks should require both hemispheres to become more engaged, while global tasks should require more from the right hemisphere.

Self-report measures of energetic arousal, tense arousal, task related and unrelated thoughts will be used to evaluate whether there are any significant differences in task difficulty, and whether these subjective reports match data found from the fNIRS.

This research will provide a clearer picture of how target features influence the vigilance decrement, which may allow for better design of jobs which require sustained attention (e.g. Industrial Inspection, monitoring of radar, sonar or other security surveillance)